

LARP

BNL - FNAL - LBNL - SLAC

LARP BEAM INSTRUMENTATION and RF

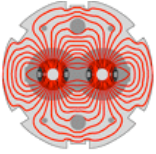
A. Ratti

LBNL

Presented at the DoE review of LARP

Fermilab

July 13-14, 2009



LARP

Outline

Overview of Beam Instrumentation Program

Summary of instruments contributed to LHC

- Schottky Monitor (lead by FNAL)

- Tune Feedback (lead by BNL)

- Luminosity Monitor (lead by LBNL)

- AC Dipole (lead by UT first, now BNL)

Highlights of FY09 activities

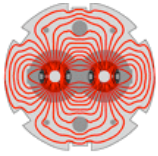
- Lumi Monitors

- AC Dipole

- LLRF Modeling

- Synch Light Monitors – New Activity

Integration and commissioning at CERN



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Instrumentation Highlights

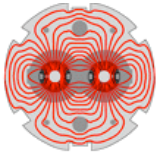
Instrumentation has contributed components that will enhance the LHC commissioning and operations

Major contributions to the LHC and US colliders

- Tune and Coupling feedback is a world first, accomplished in RHIC
- The AC dipole concept came from LARPs collaborations
now installed in all three hadron colliders
- The LHC Schottky monitor lead to the upgrade of the Tevatron system
- The luminosity Monitor is designed to survive a level of radiation 100x larger than ever seen before
- LLRF modeling expands the available tools from PEP-II operations
- Adding synch light monitoring on proton storage ring – world first

Graduate students and postdocs involved in most areas

AC dipole, LLRF, Lumi



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LARP's Instruments in LHC Commissioning

LARP instruments are installed and ready for beam commissioning

- Luminosity monitors – beam signals on day 1

- Tune and coupling – enough to publish LHC-Performance-Note-007

- LLRF modeling – LARP contributed to system tuning before beam commissioning

- Schottky monitors

- AC Dipole

New in FY09 – Synchrotron Light monitoring system – abort gap monitor

- New capability made possible by LARP's contribution

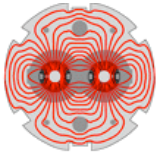
- Built by CERN

- Expected to be ready for 2009 run



Beam Signals on Lumi Monitor



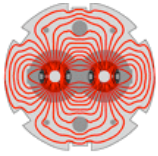


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Collaborative Efforts

LARP Instrumentation works with CERN in different ways

1. LARP and CERN equally involved in the developments and implementation
 - AC Dipole – each lab built a system for own collider
 - Tune and Coupling Feedback – System developed and tested in RHIC, CERN implemented in LHC
2. LARP did studies and provided prints, CERN implemented in LHC
 - Schottky Monitor – FNAL built processing electronics modeled after the tevatron's
 - Synch Light Monitor – study by LARP, fabrication and installation by CERN
3. LARP did most of the work, CERN provided local support only
 - Luminosity Monitors

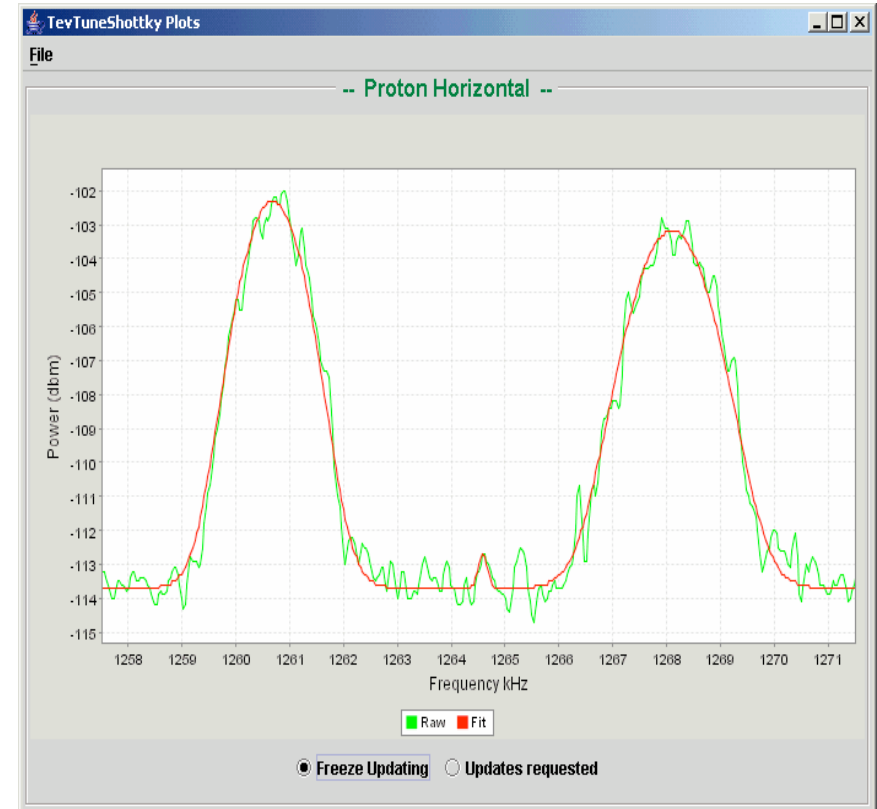


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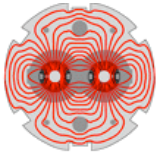
Schottky Monitors

Advanced enabling technology for:

- Non invasive tune measurement for each ring from peak positions
- Non invasive chromaticity measurements from differential width
- Measure momentum spread from average width
- Continuous online emittance monitor from average band power
- Measure beam-beam tune shift



Build in capability to monitor gain variation with time
Measure individual or multiple bunches



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Technical Approach

Center frequency of 4.8 GHz

3dB BW - 300 MHz

Sufficient for 25ns bunch spacing

Small longitudinal Z/n

No absorbers allowed

Below frequency of Schottky band overlap

Allows for adequate physical aperture

Matched pairs of SiO₂ Coax cables

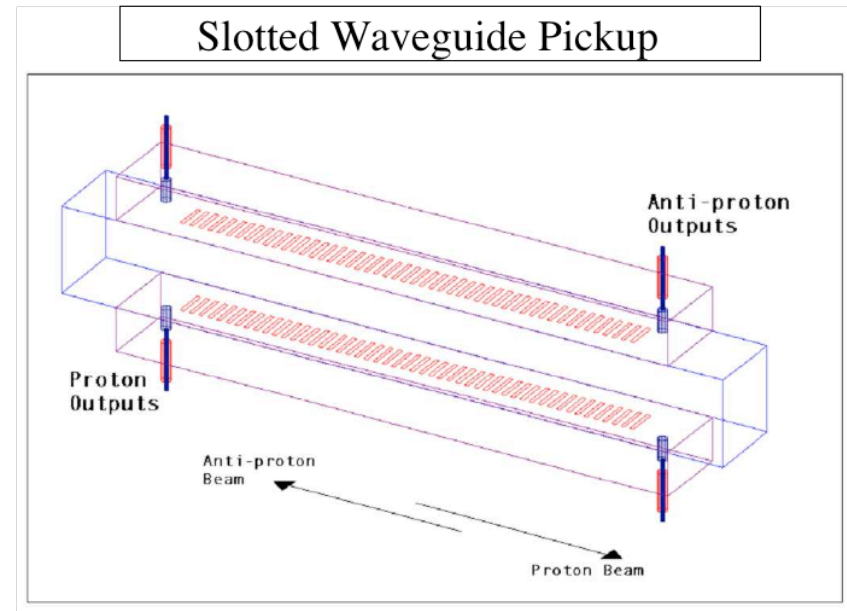
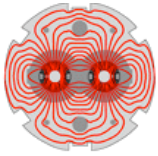


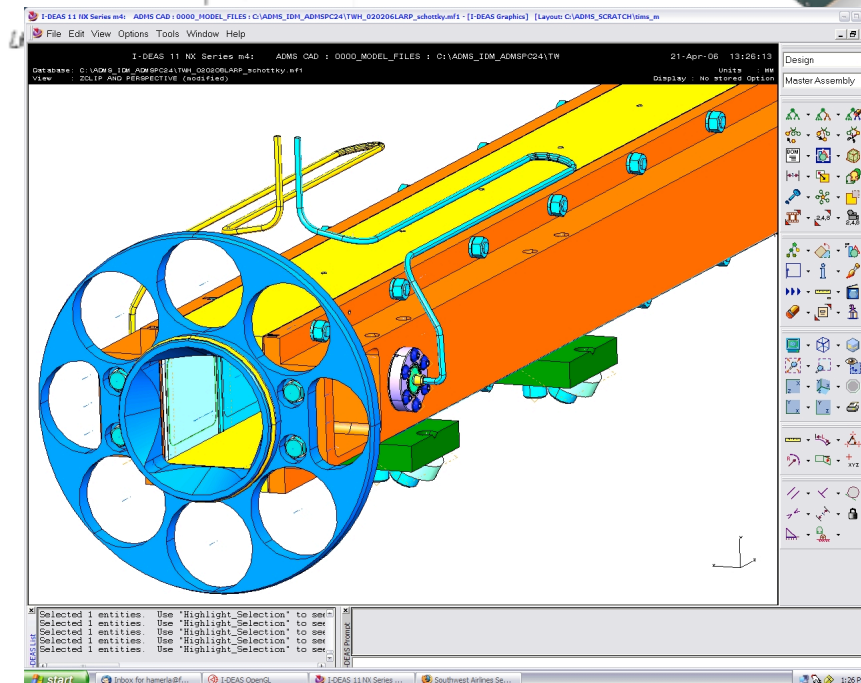
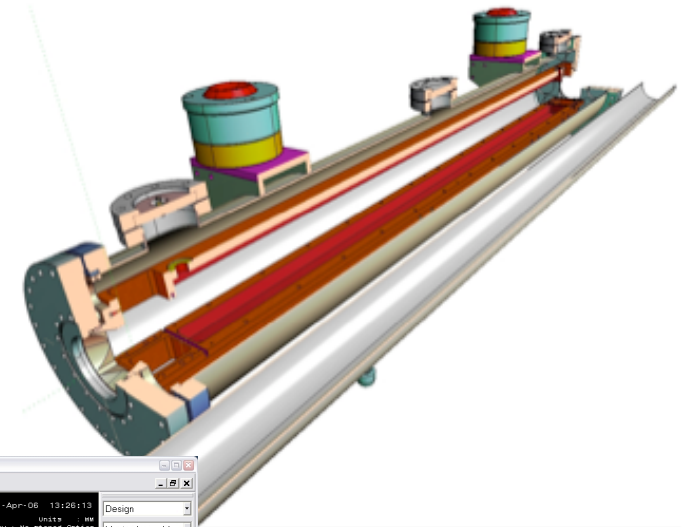
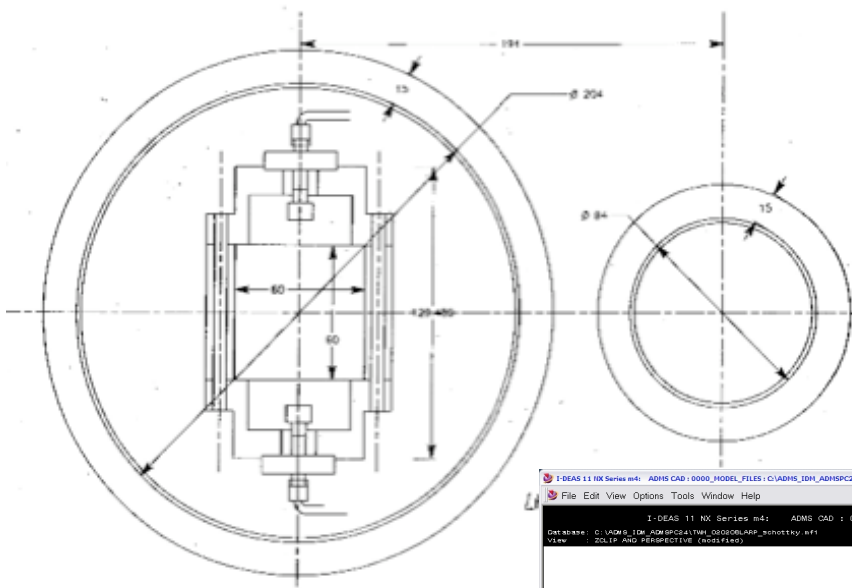
Table 1. Parameters of LHC Schottky Pickup (unit: mm)

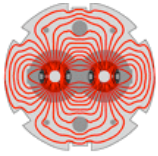
Slot length	Slot width	Slot Spacing	Number of Slots	Waveguide width	Waveguide height	Beam pipe width	Beam pipe height
20.52	2.032	2.032	246	47.549	22.149	60.00	60.00



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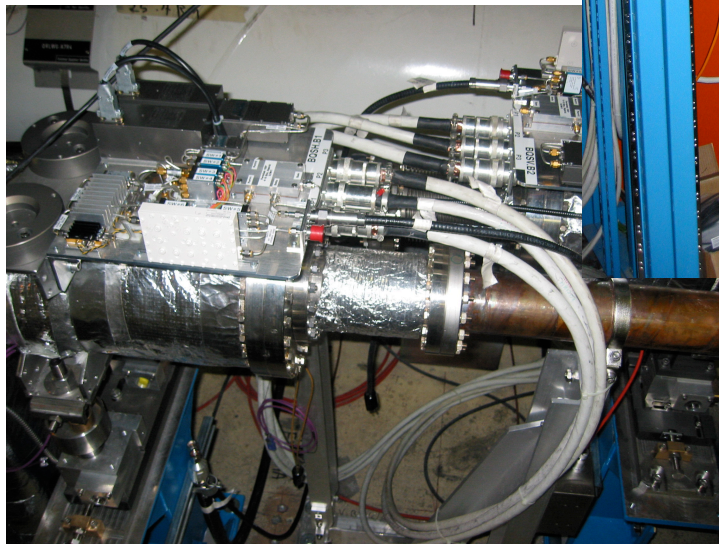
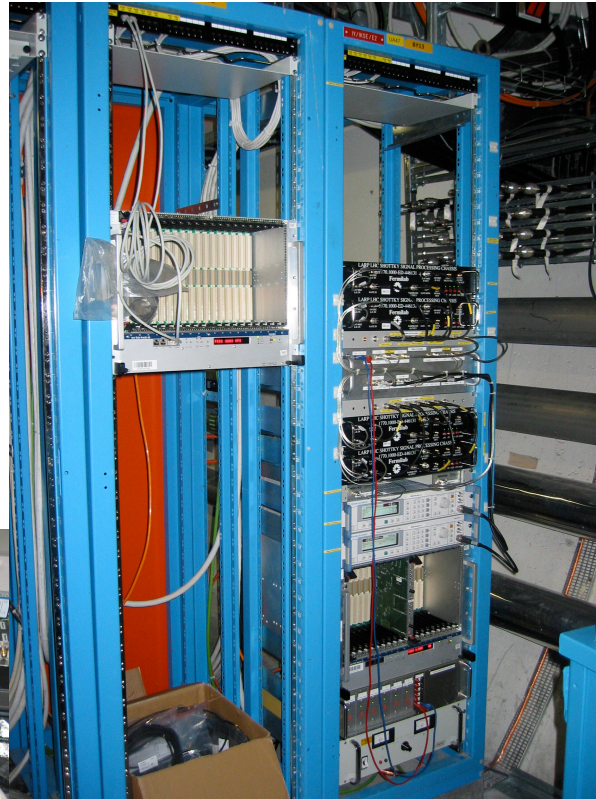
Pickup and Adjacent Beampipe Designed at FNAL





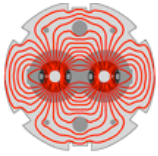
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Electronics Hardware at CERN



DoE Review June 19-20, 2008

Beam Instrumentation- A. Ratti



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Tune and Coupling Feedback

Objective: Control Tune and Coupling feedback

Develop chromaticity tracking during ramp and store

Acomplishments

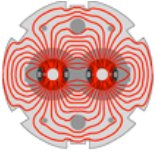
Simultaneous Tune and Coupling feedback used in RHIC run 6, **a world first**

RHIC run 7 and 8 - Tune and Coupling feedback operational
focusing on chromaticity tracking

Task ended in FY07

Moved on to chromaticity control studies

Direct Diode Detection system is an excellent tool for Beam Transfer Function Measurements



Chromaticity Tracking and Feedback

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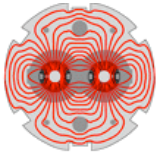
Challenge:

- persistent current effects in SC magnets can strongly perturb machine lattice, especially during energy ramp (aka “snapback”)
 - Betatron tunes ($Q_{x,y}$) and chromaticities ($Q'_{x,y} = EdQ_{x,y}/dE$) can vary significantly due to “snapback” resulting in beam loss, emittance growth.
- Effects for LHC predicted to be large.

Solution: make fast, precision Q , Q' measurements and use these signals to feedback to tuning quadrupoles and sextupoles.

This effort is ideally suited for a collaboration with RHIC, which can be the benchmark and testing ground for this effort.

- slow (1Hz) radial (1mm) modulation – next slide
- faster phase modulation – under investigation



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AC Dipole

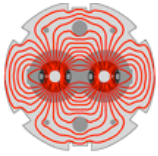
Started in FY07, lead by S. Kopp (UT, Austin)
FNAL graduate student PhD project
now Toohig fellow

VERY active involvement from BNL, FNAL and CERN

All three labs are implementing or planning for AC dipole activities

All labs contributing resources to make it happen

LARP committed to develop concepts on US colliders and provide system description for CERN to implement in LHC



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AC dipole for the LHC

FNAL TeV @ 150 GeV

Most useful @ commissioning
Measurements are FAST!

Linear optics measurement
Measure β function and phase advance
Measure β function at IP
Linear coupling measurement

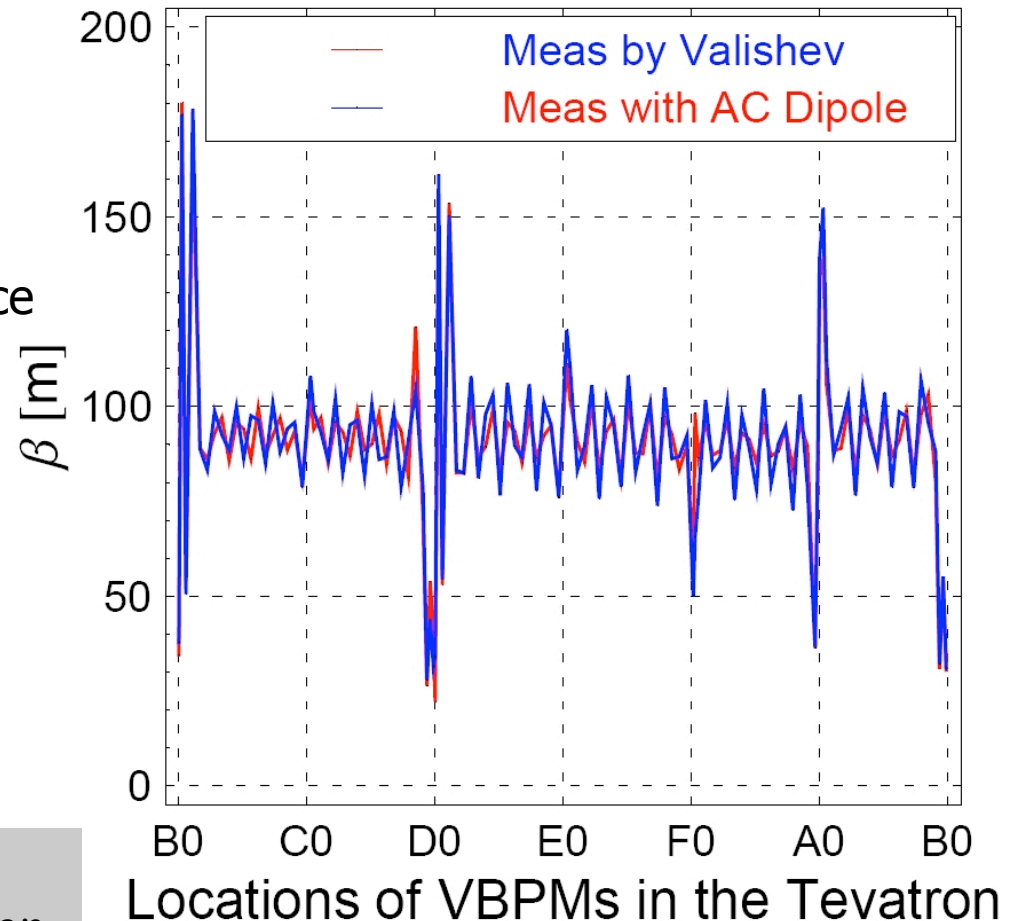
Local coupling measurement

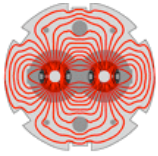
Non-linear driving term measurement

Dynamic aperture measurement

Must be

Long lasting large
coherent oscillation
with ε preserved

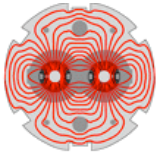




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Parameters of RHIC, TeV, and LHC

Machine	RHIC	Tevatron	LHC
E [GeV]	250	980	7000
f_{rev} [kHz]	78	48	11
γ , $1-\gamma$	0.69, 0.31	0.58, 0.42	0.3, 0.7
f_d [kHz]	55	20.5	3, 8,...
δ	≥ 0.01	≥ 0.01	≥ 0.01
$\beta_{\text{arc}}, \beta_d$ [m]	45, 11	80, 47	180, 260
σ [mm]	0.75	0.5	0.3
$\beta_d / [\text{Gm}] (4 \sigma)$	140	140	165



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FY09 Activities

Demonstrate the technique of linear gradient error correction based on the optics measurement using AC dipole at RHIC

G. Wang, M. Bai(100% BNL contribution)

Demonstrate Dynamic tuning technique with RHIC high Q ac dipole

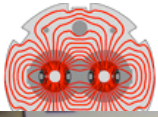
P. Oddo (100% BNL contribution)

LHC Specs

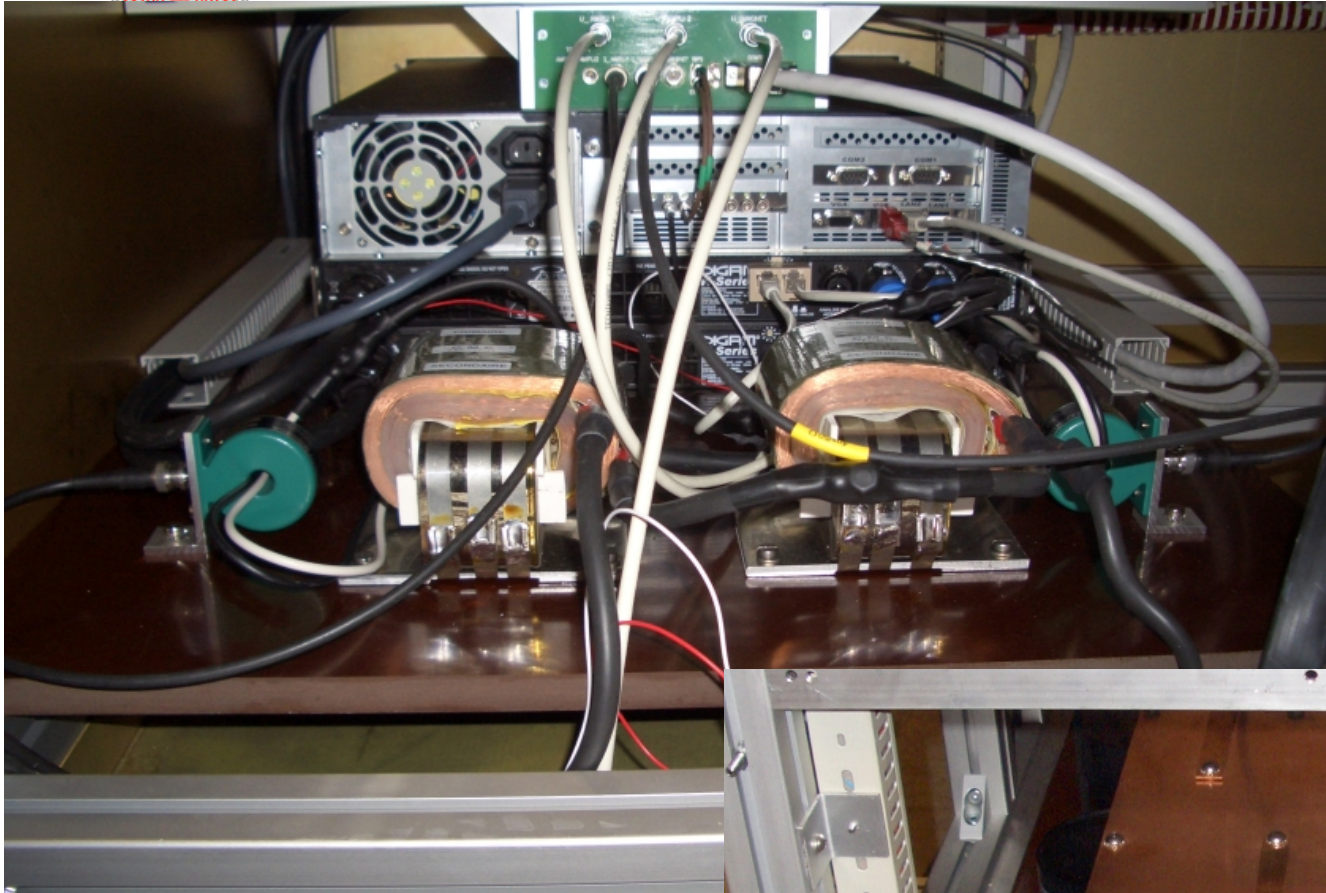
Frequency: 2750 Hz - 4000 Hz

Amplitude: 1700 A peak (4σ)

Ramping: 200 ms ramp up, 200 ms flat top, 200 ms ramp down



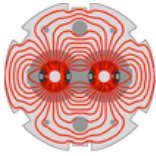
4 AC dipoles have been installed in LHC



2 magnetically coupled
audio amplifiers

“Capacitor Bank” for
frequency tuning.





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LUMI - Requirements

Requirements (Lumi mini Workshop, 16-17 Apr. 99)

- Absolute L measurement with $\delta L/L \sim 5\%$ for $L > 10^{30} \text{ cm}^{-2}\text{sec}^{-1}$
- Cross calibration with LHC experiment measurements of L (every few months)
- Sensitivity of L measurement to variations of IP position ($x^*, y^* < 1\text{mm}$) and crossing angle ($x^*, y^* < 10\mu\text{rad}$) less than 1%
- Dynamic range with "reasonable" acquisition times for 1% precision to cover $10^{28}\text{cm}^{-2} \text{ sec}^{-1}$ to $10^{34}\text{cm}^{-2} \text{ sec}^{-1}$
- Capable of use to keep machine tuned within $\sim 2\%$ of optimum L
- Bandwidth 40 MHz to resolve the luminosity of individual bunches
- Backgrounds less than 10% of the L signal and correctable

LBNL
25 Jan. 2002

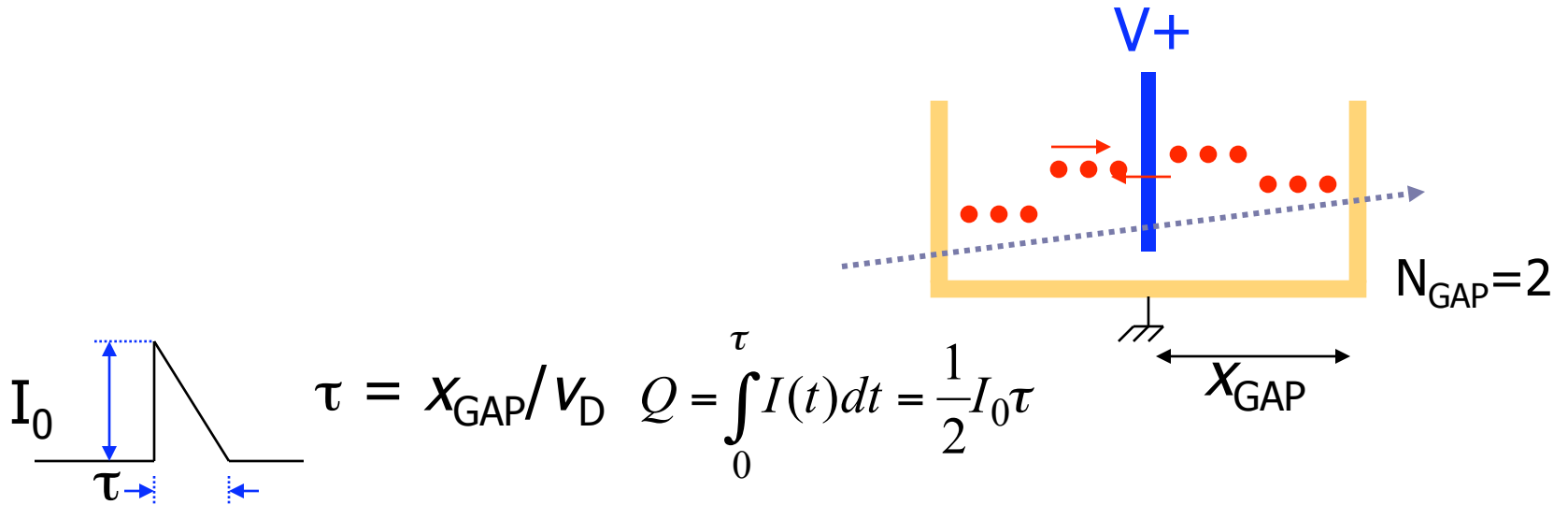
40 MHz Ionization Chamber
W.C. Turner

11

Necessary to optimize beam collisions at high luminosity IPs

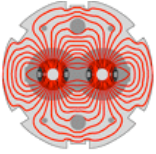


LUMI - Conceptual Design Argon Ionization Chamber



Signal is proportional to the number of parallel gaps
Capacitance add up with n. of gaps + slows down the signal

- Optimized for 6 gaps
- Must live in a radiation environment 100x worse than accelerator instruments have ever seen
 - $\sim 10 \text{ G Gy/yr}$, $\sim 10^{18} \text{ N/cm}^2$ over lifetime (20 yrs), $\sim 10^{16} \text{ p/cm}^2$ over lifetime



Ionization Chamber Fabrication

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Electrodes and ground plane

OFHC copper

Wire Electrical Discharge
Machining (Wire-EDM)

High precision

Ground plane center element
is e-beam welded

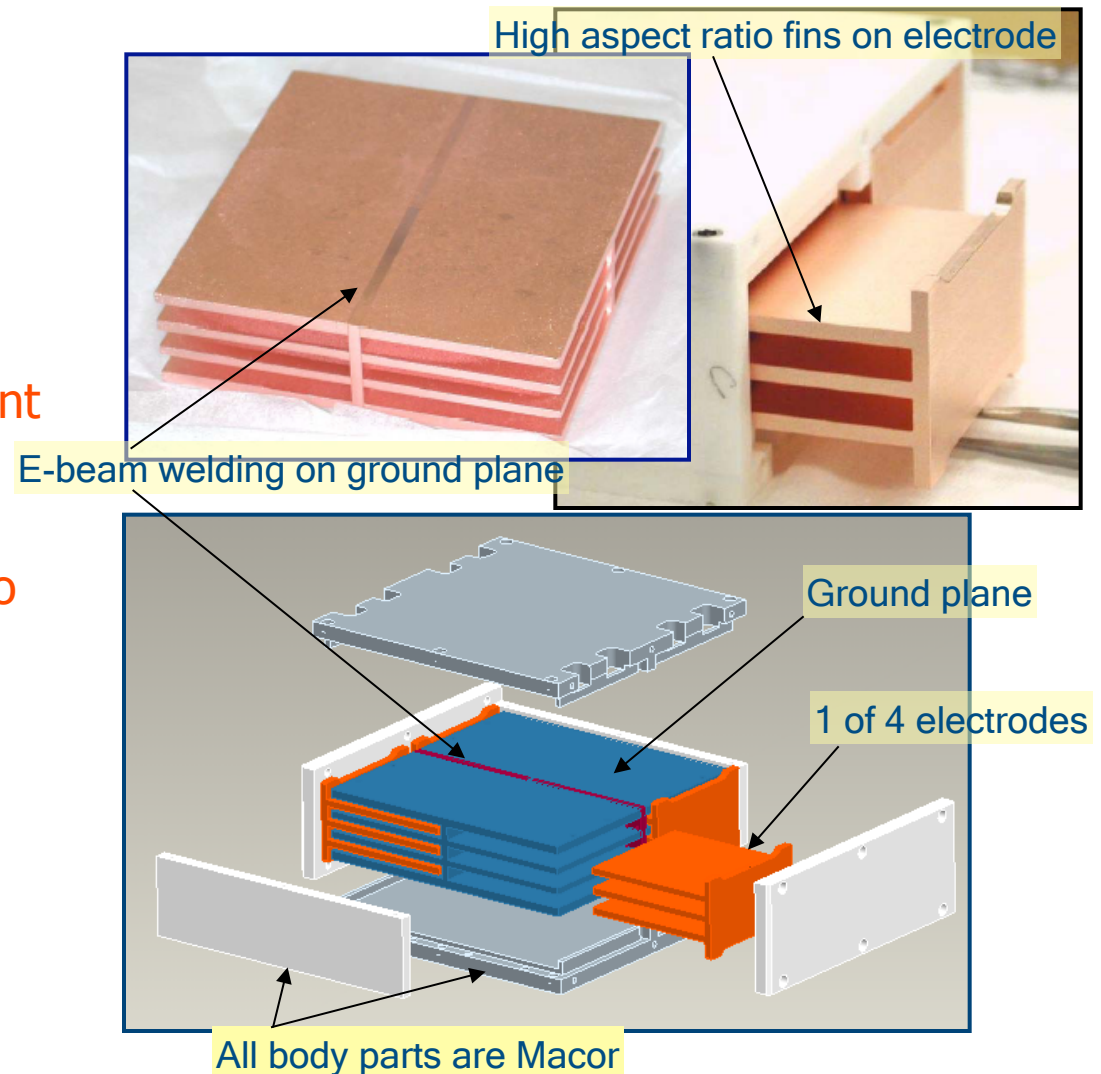
Sensor body

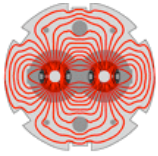
Macor (Mycalex backup also
available)

Several fine features with
high precision

Fasteners for assembly

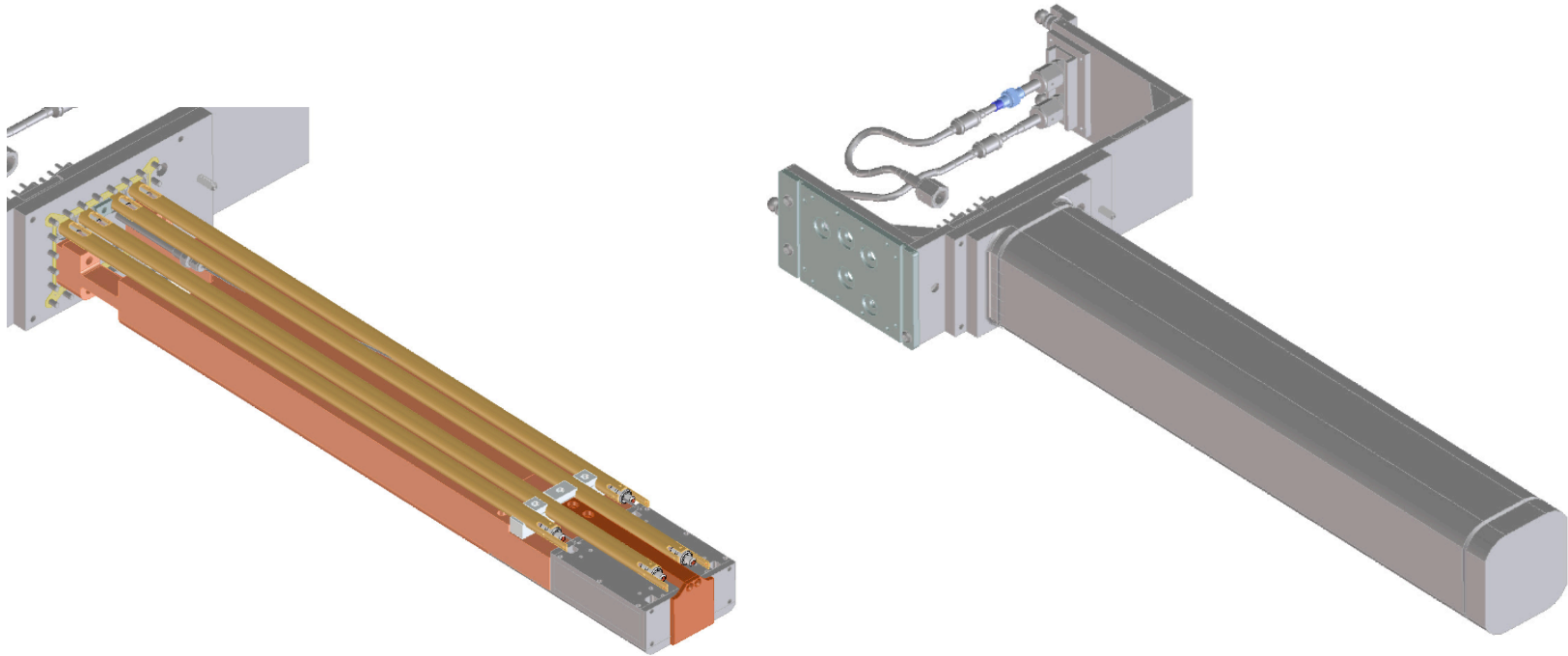
Over-constrained assembly
requires some
craftsmanship

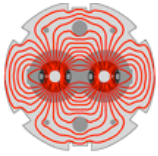




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Detector Assembly





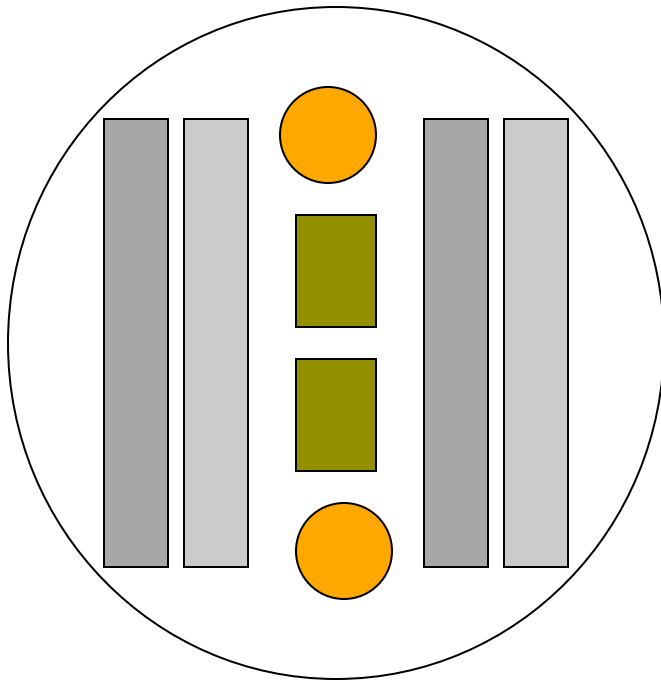
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Radiation Hardness Studies at BNL

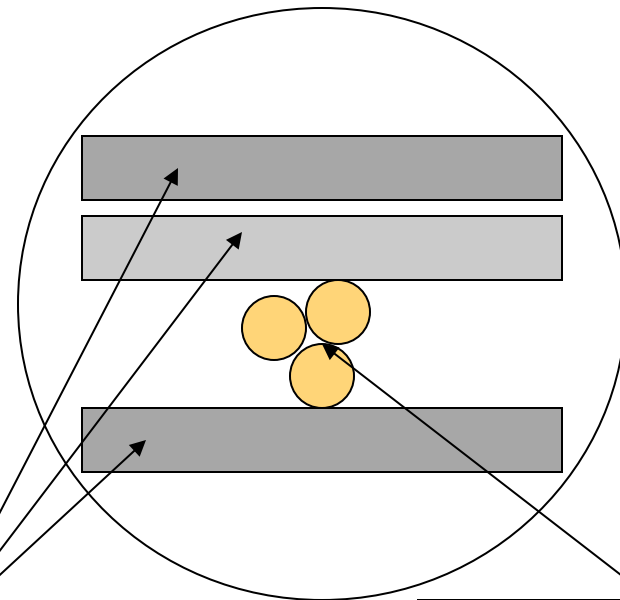
PHASE I: Irradiation with Direct Protons (~ 2 hrs) Leading to GRad-level exposure

PHASE II: Exposure to neutrons (mostly) for several days

200 MeV Proton Irradiation (direct)
Phase I (plus Phase II)

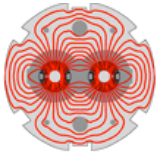


Neutron Exposure
Phase II



Ceramics (TYPE A & B)

3 2mm diam. Quartz rods



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Irradiation Tests

Proton and/or Neutron GRad-level Irradiation Exposure

Ceramics, Resistors and Capacitors

Mycalex and Macor

Metallized on one side

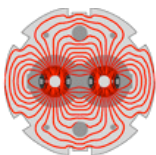
200 MeV and 117 MeV Protons at BNL Isotope Facility

Two phases

Nick Simos (BNL) ran the tests with other LHC components

Estimated 35 Grad total dose

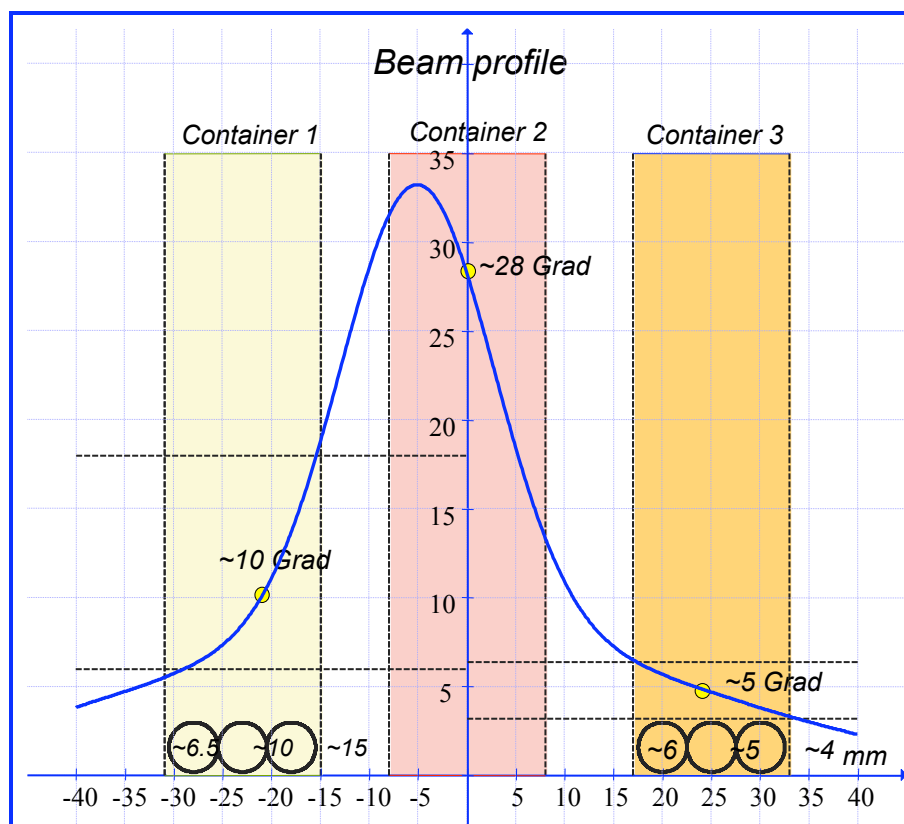
No observable problem



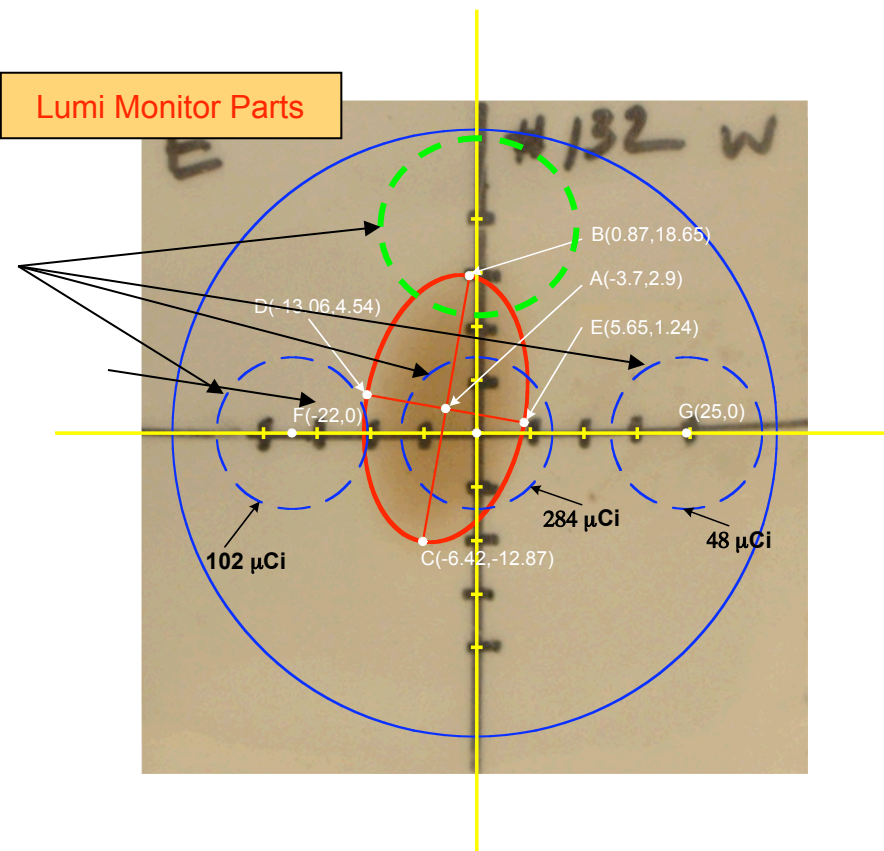
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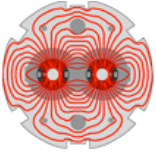
Test Condition for Phase I

Spatial Arrangement of Secondary Containers



Lumi Monitor Parts





Readout System

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Pre-amp board (in tunnel)

Signal conditioning and amplification for ~300m cable

Charge sensitive pre-amplifier capable of responding to 25 ns bunch spacing

S/N ~ 1

Shaper (in the counting room)

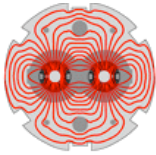
Compensates for effects of detector capacitance as well as long cables

Signals can be shared with experiments and are available in counting rooms

VME-based DAQ (in the counting room)

Hardware by CERN

Core firmware by LARP



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Project Recovery

LARP's Letter of June 2008

PMTs are welcome and an extremely helpful tool for commissioning LUMI

LARP plans to have all detectors at CERN in July, install as LHC access permits

Some electronics will be completed later in the year

Install at least one complete system to use with beam in 2008

Two detectors were installed and reading signals with beam in 2008

A full system will be tested with beam at SPS starting on June 30

Validate final design and operation of all components

Eric Prebys will attend the tests

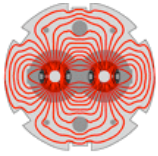
Successful test completed

No doubt all systems will be ready in 2009

All systems are ready for beam

Looking to allocate more funds to accelerate progress

Some funds were allocated and contributed to keeping the project going



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Installation of all 4 units Complete

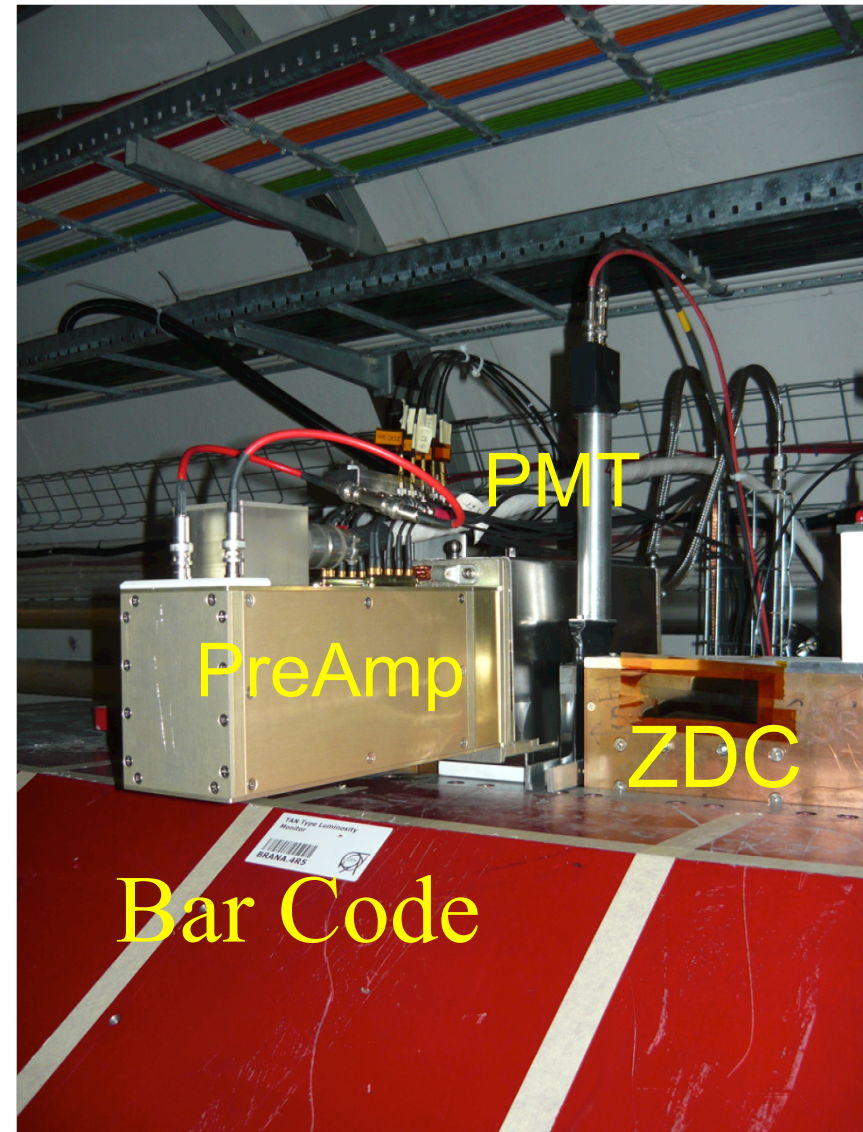
Tunnel Installations:

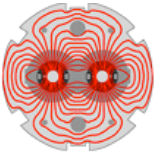
Detectors

Pre Amps

Gas connections

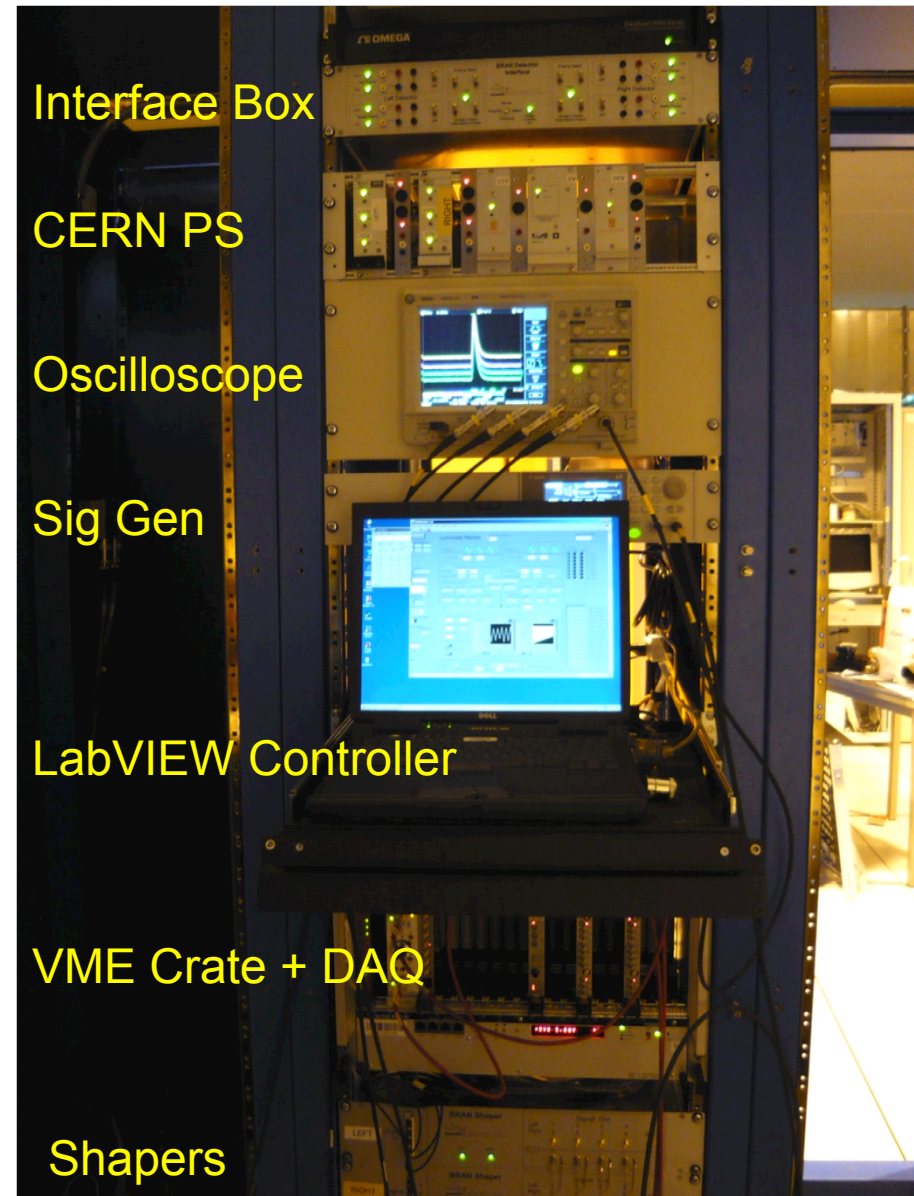
Cabling

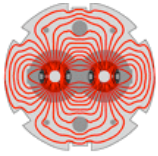




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Readout Racks

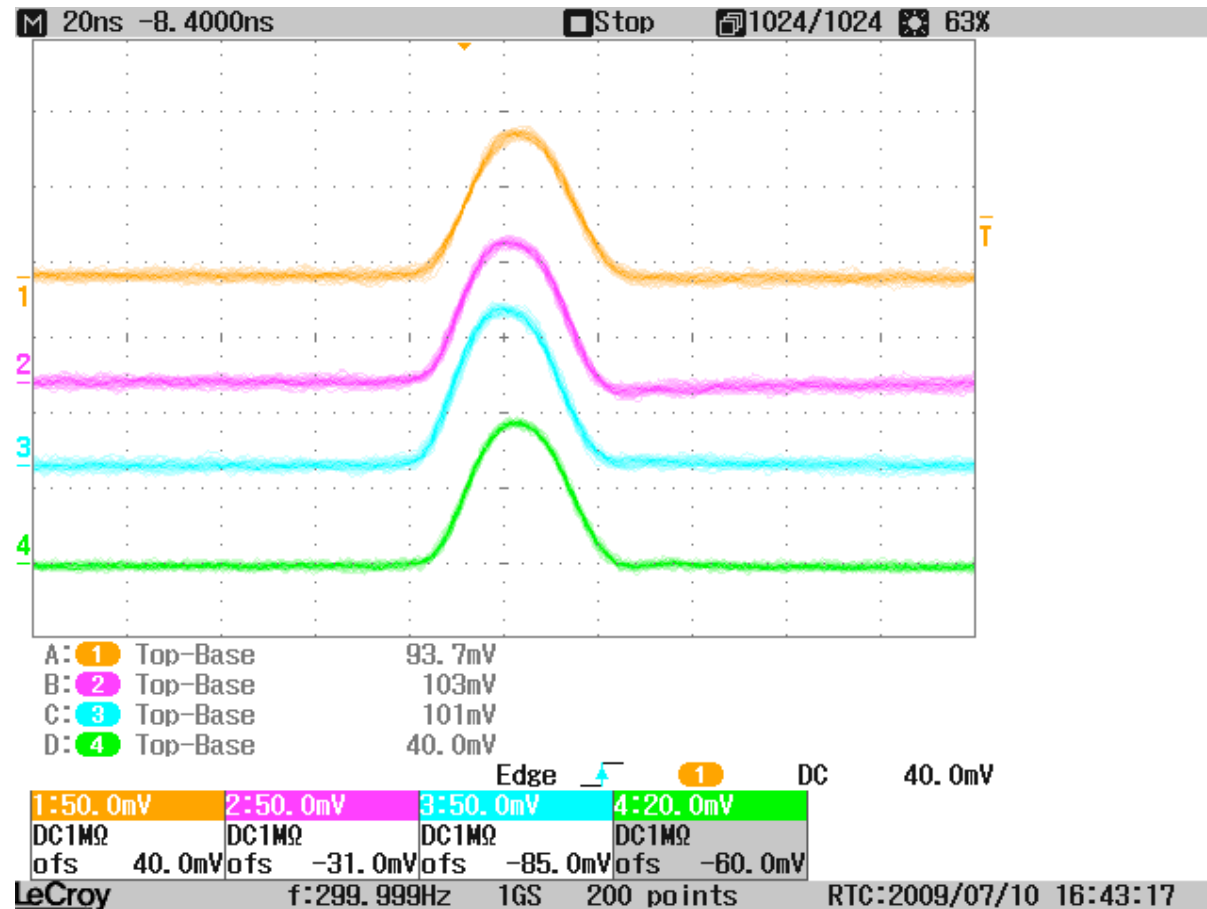


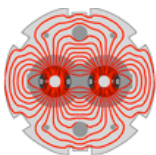


Hardware Commissioning - Analog Electronics

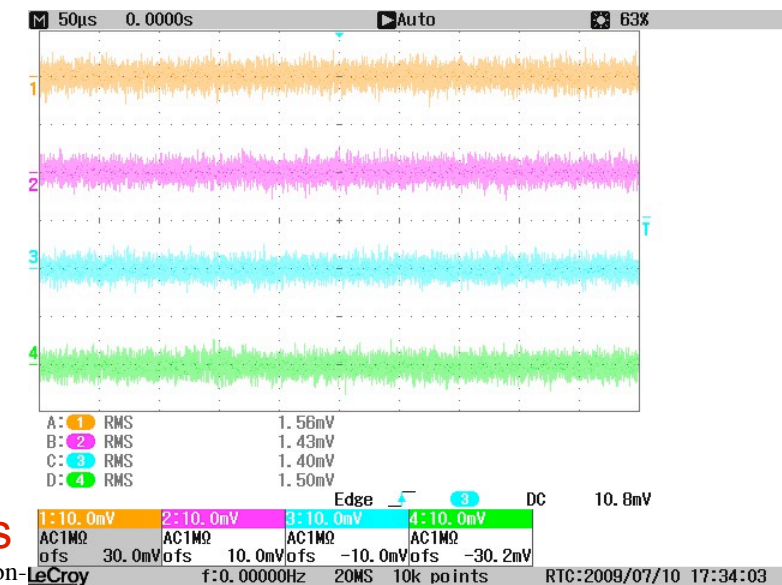
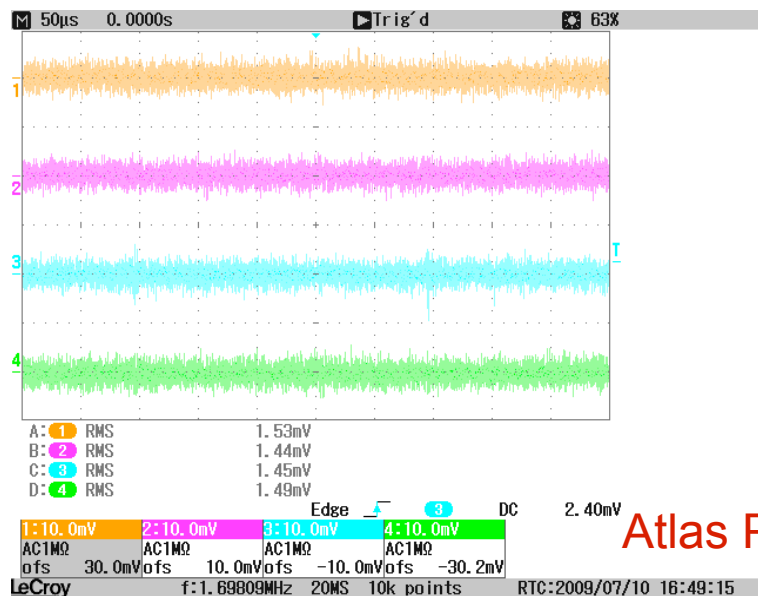
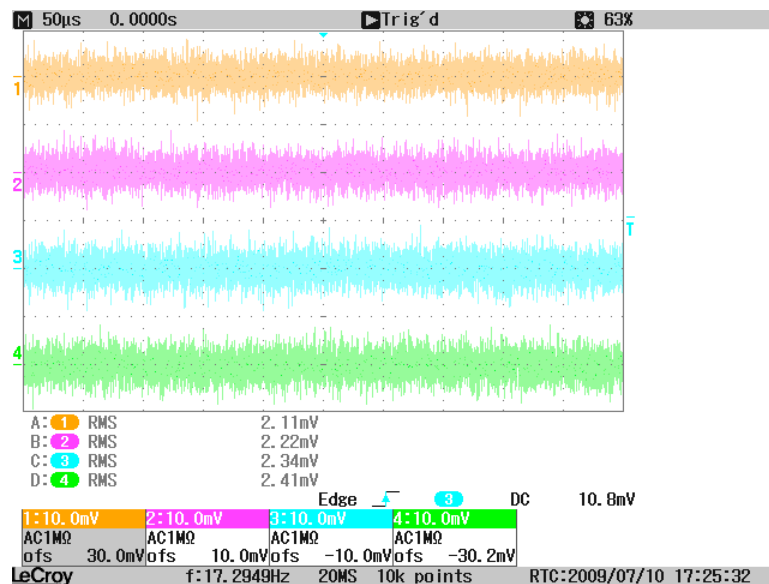
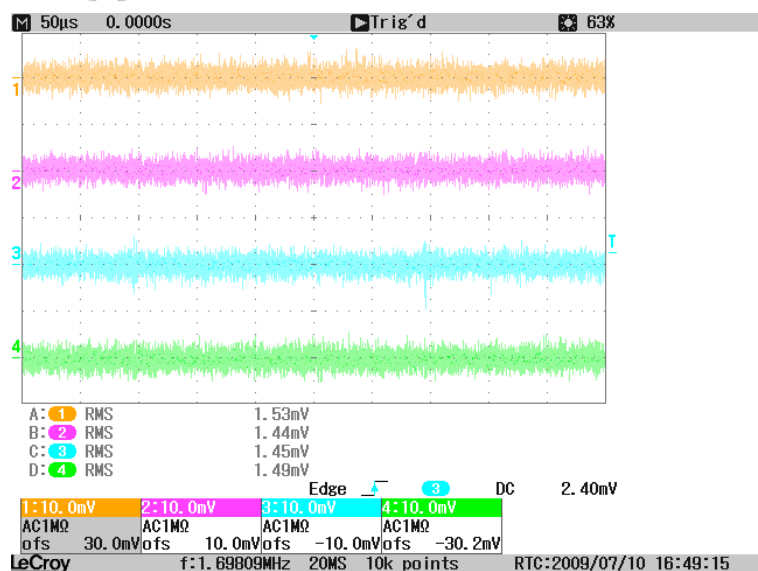
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Images of 4 noise baselines at 4 detectors



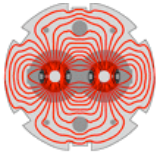


Hardware Commissioning –

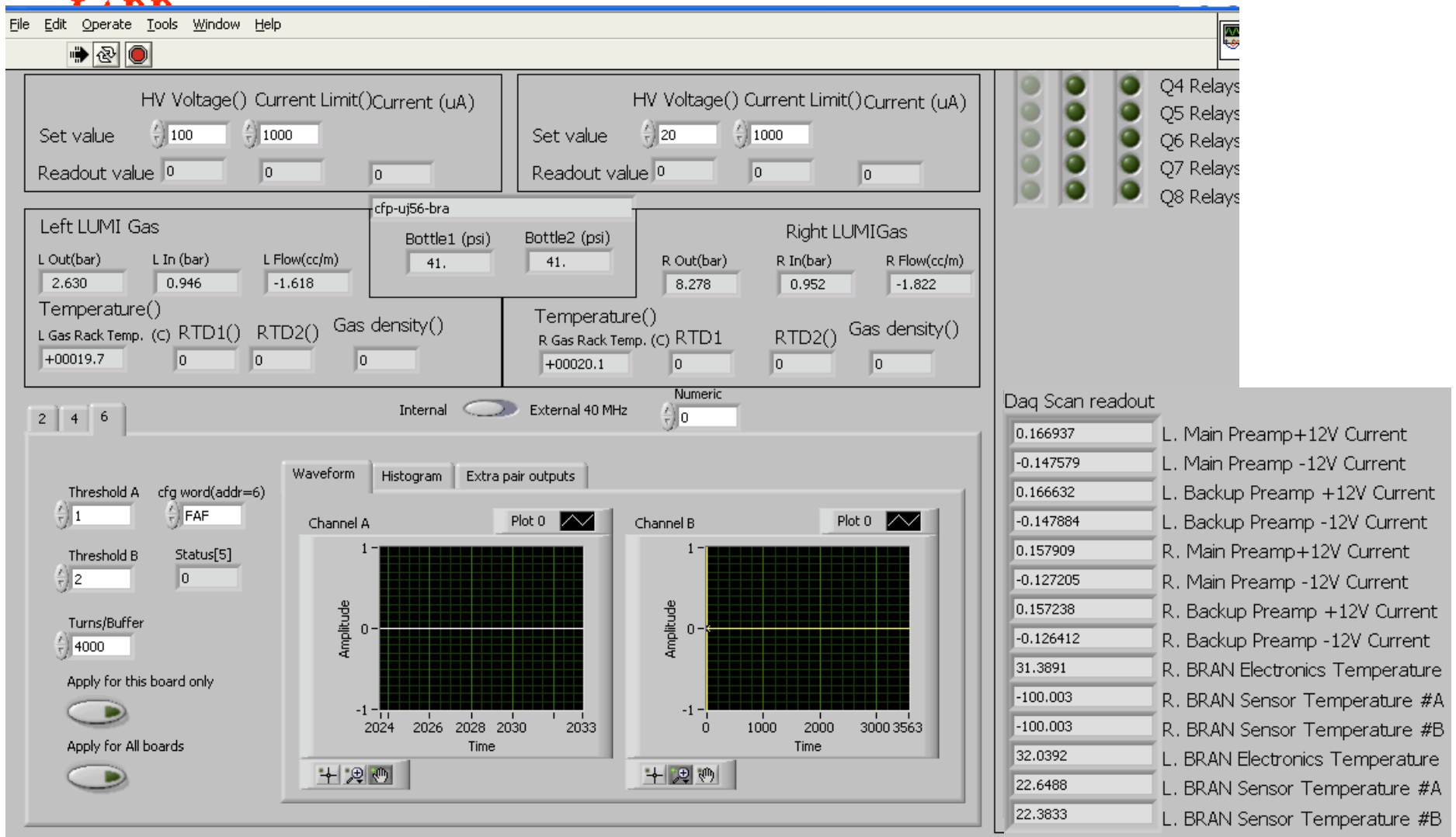


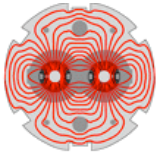
Atlas Pre-Amps

m Instrumentation-



Local Controllers (LabVIEW)





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Status Summary

All hardware delivered to CERN

Installed in final location

All signals checked out

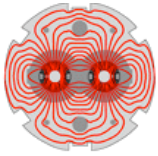
All analog chains adjusted in their final configuration

Documentation of all electronics systems delivered

Mechanical as built drawings in progress

Firmware delivered to CERN

Integration and handover planned for next two weeks



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Handoff to CERN - 1

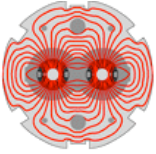
Transition period – both labs involved in installation and hardware commissioning

LBL

- Deliver all hardware
- Install and test in LHC
- Provide LabVIEW test bench

CERN

- Contribute to installation
- Actively participate in firmware development
- Develop FESA interface

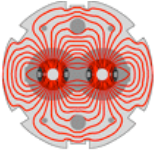


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Handoff to CERN - 2

Lumi Project Complete

1. All HW chains simultaneously lab tested for gas, HV, preamp-switching functionality with source-produced pulses processed through shapers into the LabView DAQ
2. All system units (Gas Monitors, Data Interface Boxes) working in racks with control through local PCs and with full functionality
3. Documentation of major components (detectors, preamplifier and shapers) completed, including wiring diagrams

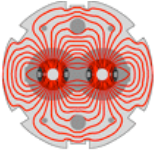


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Handoff to CERN - 3

CERN takes over responsibility for device operation and maintenance

LARP continues to be involved in beam commissioning and pre-ops
LTVs, Toohig fellows, collaborations with experiments



LARP Involvement After Project Completion

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LBL plans to assist CERN through end of September 2009

- duplicating slow readout/control functionality

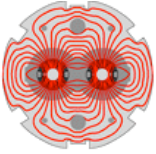
- delivering data to end users in control room or other analysis

- verifying that data from first collisions are as expected from test beam & source results

Funds could be available to LBL in FY10 to continue this effort in support of operations

- not guaranteed at the moment

LARP plans to support commissioning and operations through Toohig fellows, LTVs and possible collaborations with ATLAS and CMS



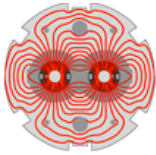
LARP

Spares

As part of the project we produced several spares which will be delivered to CERN at project end. This includes:

- one detector
- one shaper
- one preamp

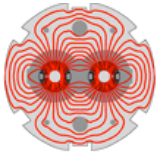
Various components and spare parts from the fabrication of the devices
Tooling and fixtures



LHC Beam Commissioning Plans

LARP

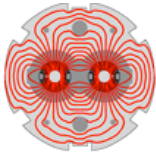
Mode	Bunches	Bunch Spacing	Luminosity [cm ⁻² s ⁻¹]	Interactions/ Xsing	Mean pulse height/ occupied bunch Xsing - mV
A–Collision studies with single pilot bunch beam - no crossing angle	1	N/A	2.5×10 ²⁶ - 3.7×10 ²⁷	0.0006-0.092	0.04-0.53
B–Collision studies with single higher intensity bunch - no crossing angle	1	N/A	1.1×10 ²⁹ - 4.3×10 ³⁰	0.27-10.71	16-611
C–Early p-p luminosity	43	2.025 μs	4.8×10 ³⁰ - 8.4×10 ³¹	0.28-4.86	15-277
	2808	25 ns	6.5×10 ³²	0.58	33
	936	75 ns	1.8×10 ³³	4.79	273
D–Nominal p-p luminosity	2808	25 ns	1.0×10 ³⁴	8.87	506
E–Ultimate p-p luminosity	2808	25 ns	2.3×10 ³⁴	20.39	1163



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Lumi Beam Commissioning Plans

- **A—Collision studies with single pilot bunch beam - no crossing angle**
 - Collision rate too low to use as a luminosity monitor
 - Minimize noise
 - Get baseline software and hardware ready
 - Study beam background (beam-gas, neutron ...)
- **B—Collision studies with single higher intensity bunch - no crossing angle**
 - Start in pulse counting mode
 - Transition to pulse height mode
 - Plan for crossing angle algorithms
 - Need sustained presence at CERN
- **C—Early p-p luminosity**
 - Develop deconvolution algorithms
 - May need deconvolution for this phase
 - Implement and test crossing angle algorithms
 - Can do pulse counting for most of this period
 - Develop pulse height mode algorithms
- **D—Nominal p-p luminosity**
 - Pulse height mode
 - Deconvolute
 - Detector needs to fully commissioned with gas flow
- **E—Ultimate p-p luminosity**
 - Might need to lower pressure to reduce voltage



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LLRF Modeling

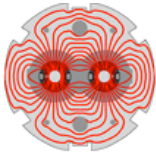
Leveraging the experience with PEP-II the group is actively working to help model the LHC RF system and its components

The goal is to adapt and expand the existing models to a hadron collider and storage ring

Supported beam commissioning by provided highly experienced engineers during the tuning and hardware calibrations before the 2008 run

Measured transfer functions, open and closed loop

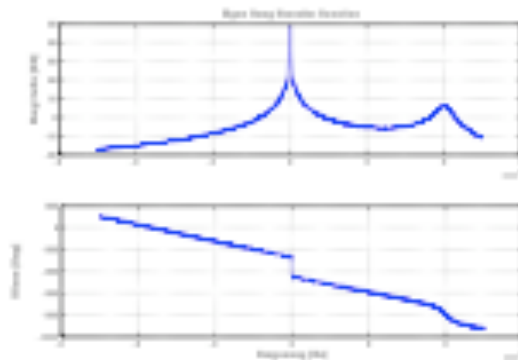
Studying noise budget by modeling key components to qualify the impact of noise on emittance growth (expected large)



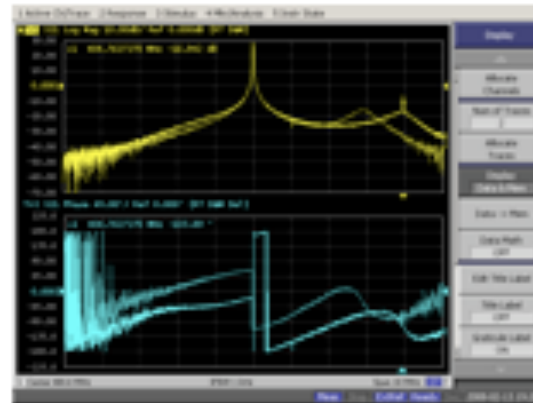
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Transfer Function Measurements

Open Loop RF Station Transfer Functions

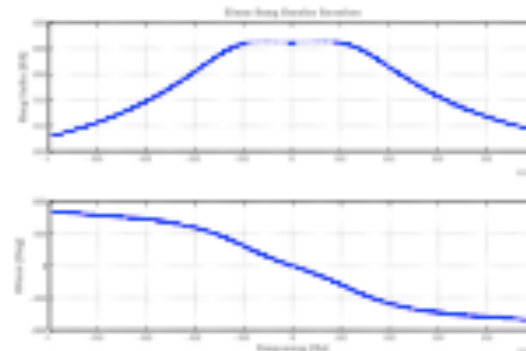


SLAC Simulated Open Loop RF station Transfer Function

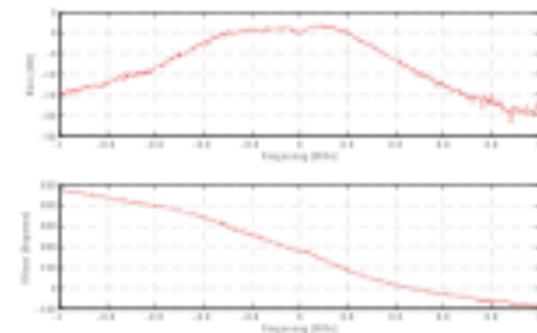


LHC Measured Open Loop RF station Transfer Function (two different RF stations)

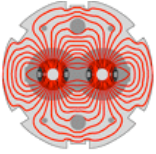
Closed Loop RF station Transfer Functions



SLAC Simulated RF station Closed Loop Transfer Function



LHC Measured RF station Closed Loop Transfer Function



Synch Light Monitors – Abort Gap

LARP

Alan Fisher- LTV from SLAC

Monitor radiation emitted by dipole bend magnets
and short undulator at low energy ($< 2\text{TeV}$)

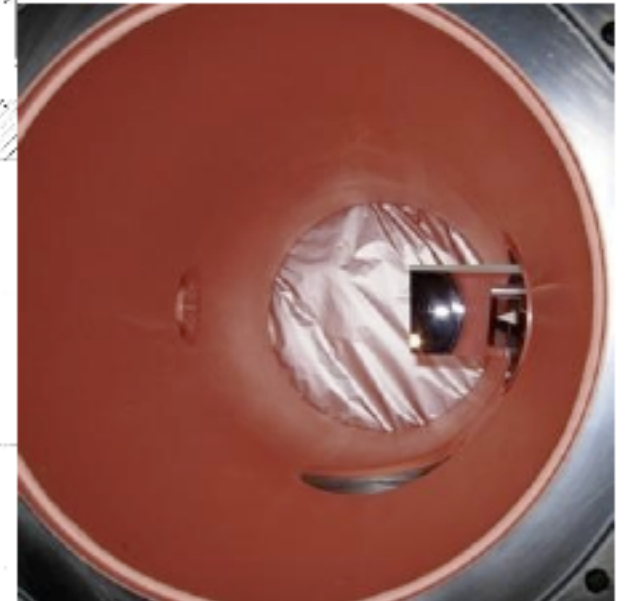
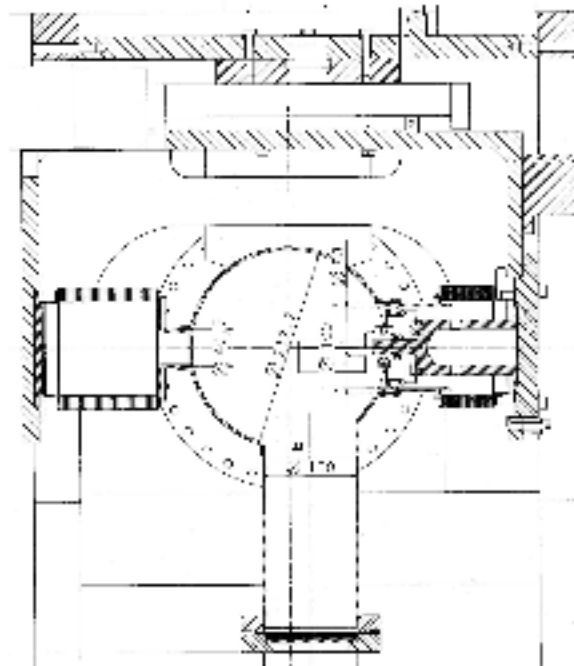
Extracted by mirror and transported/focussed by a dedicated system

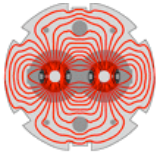
Image with cameras

Measure

beam profile and
beam in abort gap

Protons and Heavy Ions

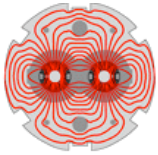




Heavy Ions Synchrotron Radiation

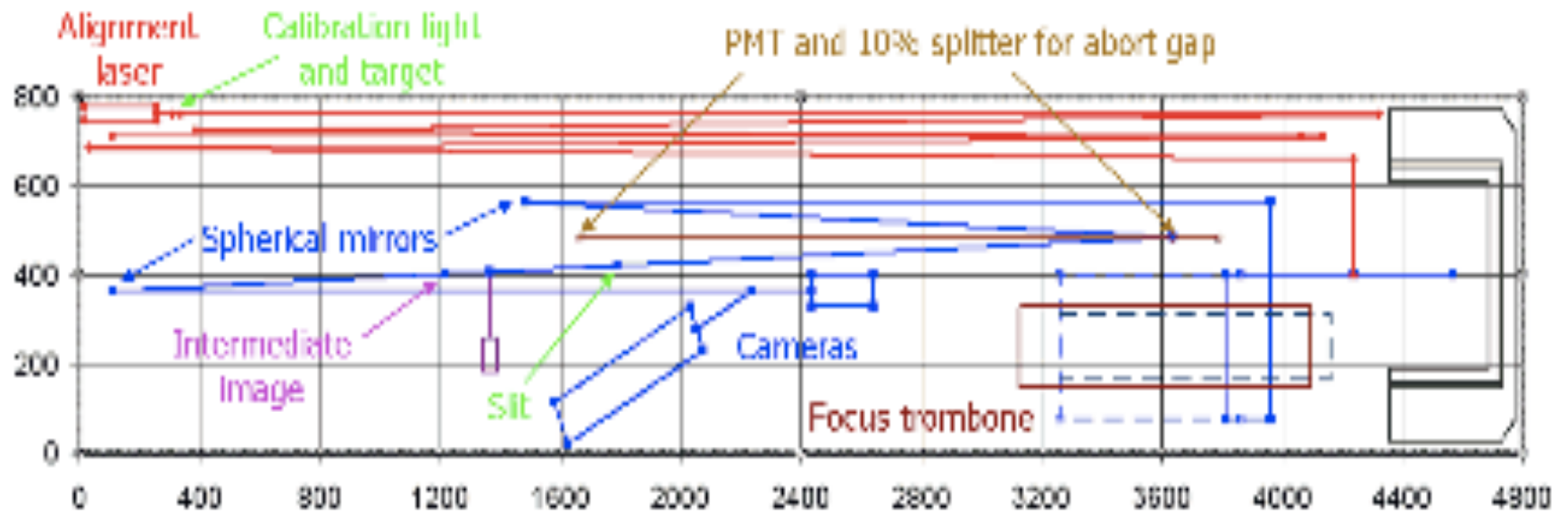
LARP

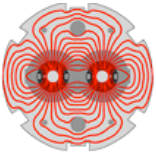
- ALICE will study collisions of lead ions.
- Planned for ~3 weeks in 2010, at the end of the run.
- Ion energy determined by maximum dipole field:
 - Inject at 36.9 TeV/ion, or 177 GeV/nucleon
 - Collide at 574 TeV/ion, or 2.76 TeV/nucleon
 - 82 times the kinetic energy of a mosquito at 1 m/s
 - Kinetic energy of a 1-mm-diameter grain of sand at 40 km/h
- Fewer bunches and fewer particles/bunch:
 - Ions: 592 bunches of $8.2 \times 10^9 = 4.9 \times 10^{12}$
 - Protons: 2808 bunches of $1.2 \times 10^{11} = 3.4 \times 10^{14}$
 - Similar quench limit



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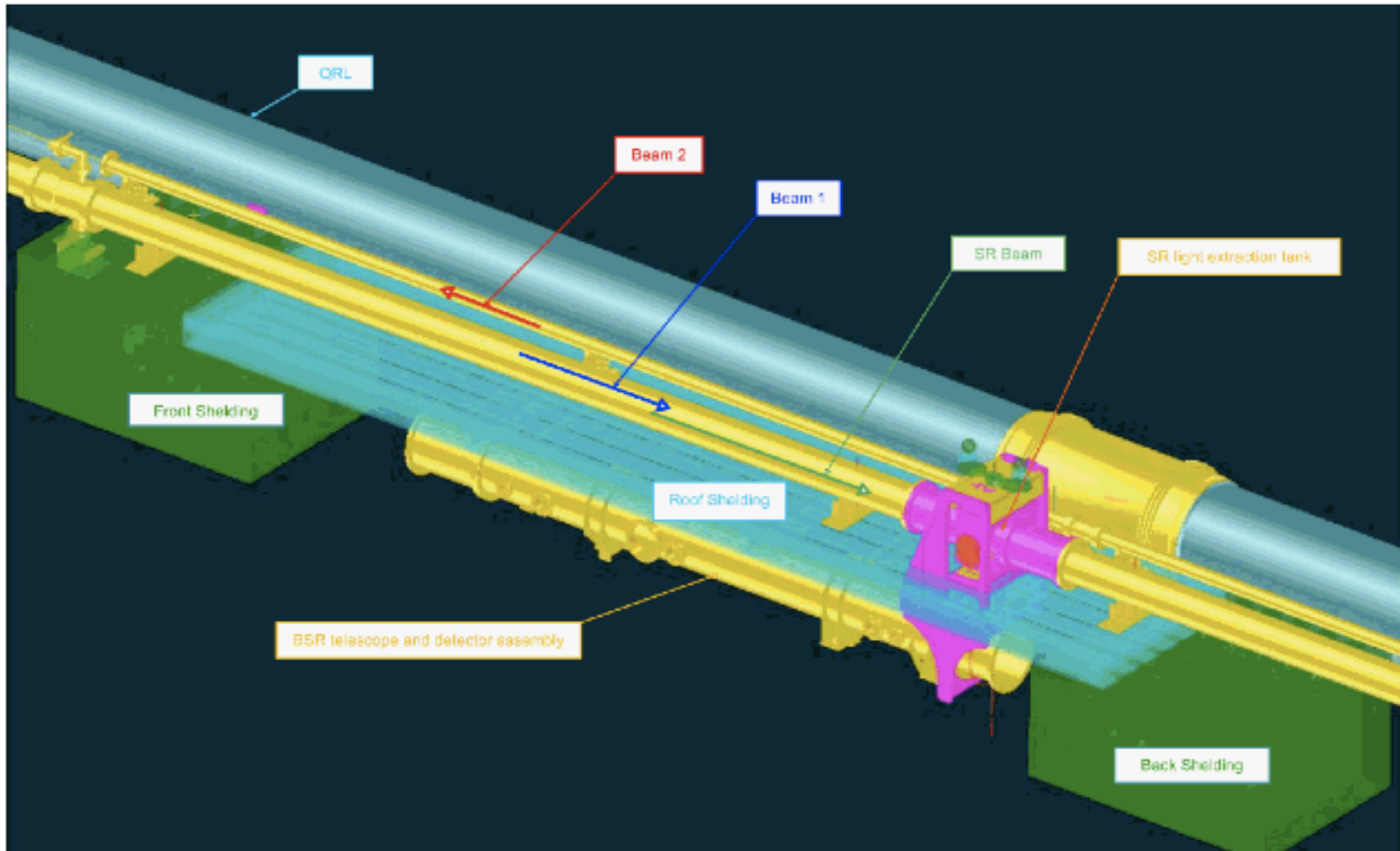
Optics Layout

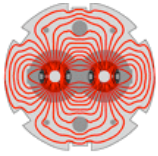




IARP

Synch





LARP

Final Considerations

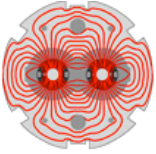
Results made possible by significant contributions from all labs

- Lumi monitor initially funded by LBL for 3 years
- AC dipole enhanced by BNL and FNAL
- Schottky monitor controls interfaces contributed by FNAL
- Synch Light Monitor (LTV) and LLRF – SLAC

Working with LARP management to secure adequate resources in support of the LHC commissioning

LTVs and Toohig fellows

Integration with beam commissioning activities is essential to the success of the instruments provided by the LARP collaboration



LARP

Summary

Spending roughly 10% of LARP's budget to date, the instrumentation program has delivered direct contributions that will help the LHC commissioning and performance improvements from day one.

Made possible by collaborations with CERN and contributions of each of the LARP labs

Adding significant, tangible contributions every year
Synch light abort gap monitor

New proposals keep coming but face reducing budgets and other priorities

This program will advance the US HEP program by
Enhancing US accelerator skills
Developing advanced diagnostic techniques that will apply to present and future US programs
Help maximize LHC performance